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Effect of under belting a multiple V-belt drive

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ABSTRACT

The paper seeks to explore the effect of under belting a multiple V-belt drive on the life of a given sets of belts. Under belting a device means using fewer belts than recommended by good design practices. The experiment investigates the incremental reduction of the number of belts by one and the attendant effect on the life of the whole belts set. The experiment is based on ten belts being the normal required to drive the load. The experiment emphasizes the effect of reducing one V belt on the life of the whole set. The experiment was based on 100% efficiency on the whole life of the whole sets from 10 belts, which is the required to drive the load. Effect of belt creep was neglected. It was progressively decreased by one and the whole belt life was evaluated based on the reduction.

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1. Introduction

Since the late 20th century, the V-belt has found extensive use as the driving element in different types of equipment. V-belt has a fiberglass reinforced neoprene jacket that protects the interior and provides a wear resistant surface for the belt [1]. Typically, V-belts are used to transmit rotary motion between shafts; find frequent application where synchronization between shafts is not important because they are subject to certain amount of creep and slip. Transmission of torque between pulleys results in speed losses arising from belts elastic creep [2]. According to Gerbelt [3] slippage mechanism occurs due to regions of non- slippage and slippage acting along the arc of contact between belt and pulley. Contributing further to the slip theory in [4] considered flexural rigidity and compressibility of the belt; belt speed, differences due change of radius of curvature of the belt as factors to explain slip behaviors.

V-belts are made to standard length and cross -sectional sizes, the details of which can be found in catalogues [5], [6]. The grooved pulleys that V-belt run in are called sheaves. They are usually made of cast iron, pressed steel or die cast material. Normally, V-belt drives operates best at speed between 8 to 30 m/s. For standard belts, ideal (peak capacity) speed is about 23m/s. Narrow V-belts; however, operates up to 50m/s.

V-belt has replaced the convectional flat belt drive in many fields of application because of its inherent advantages. Its advantages over chain and gear drive are flexibility, elasticity, and simplicity; besides, it provides a compact, quiet, and resilient type of power transmission. As against flat belt and rope drives, it needs considerably less space.

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Nomenclature

C	Center to center distance (mm)
D	Large sheave diameter (mm)
d	Small sheave diameter (mm)
F	Initial tension (N)
F_1	Tension on the tight side (N)
F_2	Tension on the slack side (N)
Fb_1	Induce tensile stress (driver) pulley (N)
Fb_2	Induce tensile stress at the driven pulley (N)
F_c	Centrifugal tension (N)
F_i	Effective coefficient of friction (N)
Fos	Factor of safety
H_a	Allowable power per belt (W)
H_d	Design power (W)
H_{nom}	Nominal power (W)
H_{tab}	Tabulated power of a belt (W)
K_1	Angle of wrap correction factor
K_2	Belt length correction factor
K_b	Belt width factor
K_c	Speed ration factor
K_s	Service factor
L_p	Pitch length (mm)
N_b	Number of belt
N_d	Design factor
N_p	Number of passes
T	Life time (hours)
V	Peripheral speed (m/s)

Greek letters

θ	Angle of contact (rad)
Φ	Sheave groove angle (rad)
ΔF	Change in tension (N)

It is versatile in application, requires little maintenance, cheap and has a long life between 5 to 10 years [5]. Its slip free power transmission enables its efficiency to reach nearly 100% although it is still debatable [7]. It has impact and vibration damping effect. The included angle for the V- belt is usually from 30^0 to 40^0 [6], [7].

V-belt durability in terms of belt life can be seriously affected by many factors. Belt durability (life) is greatly influenced with temperature changes, improper belt tension, mismatching of belt length and use of fewer numbers of belt than necessary (under belting). Studies aim at a deeper understanding of belt life evaluation during power transmission undertaken in [8]. In this study, temperature rise as the response of interest was considered in addition to input variables such as pulley diameter, bending frequency, braking torque and pretension in the regression model developed. The results of the analysis of variance (ANOVA) reveal that the pulley diameter was the most influential parameter affecting the objective function. Balta et al. [9] studied the effect of belt drive parameter on speed losses in V-ribbed belt drives. The study determined the effect of each input parameter on V-belt speed losses and the optimum operating parameters was established using the response surface methodology. The reliability and lifetime distribution of belt drives were undertaken in [10] where input parameters such as geometric, material, motion and dynamic properties of the belt drive system were employed in the analytical dynamic model developed. The result of the dynamic model simulation carried out shows that stiffness degradation, which a function of the material parameter has an incredibly significant effect on the developed model.

Durability life correlation or belt life evaluation has been of tremendous interest to many researchers (belt producing companies) [5], [11]. These parameters are calculated on the basis for power ratings of V-belt but depend somewhat on the manufacturer. It is not often mentioned quantitatively in literature, but it is available from vendors. Some bases are in several hours e.g. 24,000 hours or a life of 10^8 or 10^9 belt passes as the case may be. Some producer makes use of standard recommended time of 26,000 hour [12]. The consideration is hinged on the condition that the rating, whether in terms of hours or belt passes is for belt running on equal diameter sheave (180^0 of wrap), of moderate length and transmitting steady load [5].

The basics of this paper is anchored on evaluation of the effect of using fewer numbers of belt on the overall life of the whole sets of belts using number of passes and lifetime in hours approach. Experimental design and analytical calculation were used for both approaches. Comparison of the experimental and analytical approach was evaluated. Deviation from this experimental test conditions were acknowledged by adjustment.

1.1. Designation of V-belt

A V-belt sizes are specified by a code designation consisting of symbols representing belt cross section followed by a designation of length. For example, a conventional V-belt designated B23 has a B cross section and a 584.2mm. Standard length designation: a narrow belt designated 5V350 has 5V cross section and a belt length 889mm. A light duty V-belt designated 2L080 has a 2L cross section and an effective outside length of 2032mm [13].

1.2. Belt Drive Analysis

$$L_p = 2C + \pi(D+d)/2 + \pi(D-d)^2/4C \quad (1)$$

$$C = 0.25[\{L_p - \pi/2(D+d) + \sqrt{L_p - \pi/2(D+d)^2}\} - (D-d)^2] \quad (2)$$

$$H_a = K_1 K_2 H_{tab} \quad (3)$$

$$(F_1 - F_c)/(F_2 - F_c) = \exp(0.5123\,\theta) \quad (4)$$

$$H_d = H_{nom} K_s N_d \quad (5)$$

$$N_b = H_d / H_a \quad (6)$$

$$F_c = K_c (V/1000)^2 \quad (7)$$

$$\Delta F = F_1 - F_2 \quad (8)$$

$$\Delta F = \frac{63025 * H_d / N_b}{n(d/2)} \quad (9)$$

$$F_1 = F_c + \frac{\Delta F \exp F_i \Phi}{\exp F_i \Phi - 1} \quad (10)$$

$$F_2 = F_1 - \Delta f$$

$$F_i = \frac{F_1 + F_2}{2} - F_c \quad (11)$$

$$Fos = H_a N_b /(H_{nom} K_s) \quad (12)$$

$$T_1 = F_1 + (Fb)_1 = F_1 + K_b / d \quad (13)$$

$$T_2 = F_1 + (Fb)_2 = F_1 + K_b / D \quad (14)$$

$$T^b N_p = K^b \quad (15)$$

$$1/N_p = (k/T_1)^{-b} + (k/T_2)^{-b} \quad (16)$$

$$N_p = [(k/T_1)^{-b} + (k/T_2)^{-b}]^{-1} \quad (17)$$

$$T = N_p L_p / 720V \quad (18)$$

The constants k and b have their ranges of validity. If $N_p > 10^9$, report that $N_p > 10^9$ and $T > N_p L_p / 720V$ without placing confidence in numerical values beyond the validity interval.

2. Methods

The method used consists essentially of two set of values derived experimentally and analytically. The experimental values were extracted from Fanner International Metric belt drive catalogue [12]. The generated values were replicated using Centrifuge SA 100, a continuous line Machine having a working speed of 1500rpm transmitting steady load with 10 belts pulley groove, having equal driving and driven sheave diameter (angle of wrap 180^0). The analytical method entail substituting the values into the equations (17) and (18) for durability (belt life) correlation in terms of the number of passes or lifetime in hours. The number of belt was reduce steadily by one and the number of passes and lifetime in hours was generated for 9, 8, 7 and 6 belts.

The generated values for the experimental and analytical was subject to statistical regression using the single variable linear model as a predictor of belt life in terms of belt passes based on the number of belts. The strength of the relationship was also estimated statistically using coefficient of determination equation.

The generated value of lifetime in hours was plotted against number of belts. The equation was linearized in the form of straight-line graph as follows:

$$T = a + bN_b \quad (19)$$

Where *a* is the intercept on the graph and *b* is the slope. Equation (19) is a better predictor of the behavior of number of belts against lifetime in hours.

Assumption made: All other factors like temperature change, improper belt tension, mismatching of belt length, friction, slip, belt material, velocity etc., were assumed to be constant. Table 1 shows the experimental reading.

Table 1 Experimental results [12]

N_b	N_p	T (h)	Decrease in belt life (%)
10	1,000,000,650	105,370	100
9	700,000,000	73,759	70
8	450,000,000	47,416	45
7	280,000,000	29,504	28
6	170,000,000	17,913	17

3. Results and Discussion

The generated results are presented in Tables 2 – 4 and Fig. 1. From experimental findings, coefficient of determination is deduced as:

$$r^2 = \frac{[n\Sigma N_{b1} T_1 - (\Sigma N_{b1})(\Sigma N_{b1})(\Sigma T_1)]^2}{[n\Sigma N_{b1}^2 - (\Sigma N_{b1})^2]][n\Sigma T_1^2 - (\Sigma T_1)^2}$$

$$r^2 = \frac{1{,}200{,}766{,}682{,}000}{1{,}257{,}042{,}467{,}000} = 0.95 \quad (20)$$

Table 2 Analytical calculation

N_b	N_p	T (h)	Decrease in belt life (%)
10	1181267891	124470	100
9	897763597	94597	76
8	614259303	64440	51
7	378005725	39830	32
6	141752146	14936	12

Table 3 Experimental computation

T (h)	N_b	$T_1 N_{b1}$	N_{b1}^2	T_1^2
105370	10	1053700	100	1102836900
73759	9	663831	81	5440390081
47416	8	379328	64	2248277056
29504	7	206528	49	870486016
17913	6	107478	36	320875569
273962	40	2410865	330	9982865622

Table 4 Analytical computation

Lifetime, T (h)	Number of belts, N_b	$T_1 N_{b1}$	N_{b1}^2	T_1^2
124470	10	1244700	100	154927809000
94597	9	851373	81	8948592409
64440	8	515528	64	4152513600
39,830	7	278810	49	1586428900
14936	6	89616	36	223084096
$\sum T = 338273$	$\sum N_b = 40$	$\sum T_1 N_{b1} = 2980027$	$\sum N_{b1}^{2=} = 330$	$\sum T_1^2$

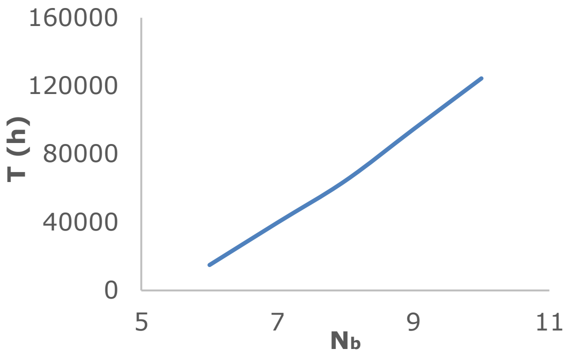

Fig. 1. Numbers of belt against lifetime in hours

Similarly, for analytical method:

$$r^2 = \frac{[5 \times 2980027 \; - \; 40 \times 338273]^2}{[5 \times 3330 - (40)^2][5 \times 3040339991\ 0 - (338273)^2]}$$

$$r^2 = 0.98 \qquad (21)$$

For the linear approach model of equation (19)

$$a = \frac{\sum T_1}{n} - \frac{b \sum N_b}{n}$$

$$b = \frac{n \sum N_{b1} T_1 - [(\sum N_{b1})(\Sigma T_1)]}{n \, \Sigma N_{b1}^2 - (\Sigma \, N_{b1})^2}$$

$$b = \frac{5 \times 2980027 \; - (40 \times 338273)}{5 \times 330 \; - (40)^2}$$

$$b = 27{,}384.3 \qquad (22)$$

$$a = \frac{338{,}273}{5} - 27{,}384.3 \times \frac{40}{5}$$

$$a = -151{,}427.8 \qquad (23)$$

$$T = -151{,}427.8 \; + \; 27{,}384.3 N_b \qquad (24)$$

Equation (24) describes the straight line graph, which is the best predictor of time in hours, based on varying number of belt N_b. The value of r^2 represents the proportion of variation of lifetime, *T* (in hours) that is explained by the relationship with number of belt N_b. The coefficient of determination r^2 is the strength of relationship; a value of r^2 = 0.95 indicate 95% of the variation in *T* is produced or explained by the regression line with N_b. Also, for the analytical r^2 = 0.98 indicating 98% of variation in *T* while the remainder 2% is due to chance. In this case, a quite reliable forecast for T can be obtained when the value of N_b is known.

4. Conclusion

This study presents durability (life) correlation approach using number of passes and lifetime in hours in evaluating the belt life of the multi belt system. The approach in this paper is centered on belt running on equal diameter sheave (180^0 of wrap) of moderate length and transmitting steady load. The approach presented in this paper is confined to the analysis of belt life in terms of hours and number of passes using experimental and analytical techniques. However, constraints like drive having different sheave diameter was not considered.

As applicable to the industry: it is advisable for industry using multi belt machines to have different sets of belts as backup in case of failure. From the analysis, it is discovered for a Multi belt drive, failure of a belt reduces the whole belt life by 30% while failure of 2 reduces it by about 55%. Therefore, the effect of under belting is undesirable. It is also imperative for belt tension to be checked frequently, due to normal stretching during operation. Even if there is no failure, tension should be checked regularly and reset throughout a belt operating life.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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